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Integrating Digital Learning, Local Knowledge, and Community Participation to Enhance Elementary Students' Disaster Awareness

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Abstract

Disaster education for elementary students often remains information-oriented, while digital learning, local knowledge, and community participation are frequently examined separately rather than as an integrated pedagogical approach. This study examined whether integrating these three elements through the Ethno-Social Community-Based Digital Disaster Learning Model was associated with a greater improvement in student disaster awareness than conventional instruction. A quasi-experimental non-equivalent control group design involved 400 fifth-grade students from disaster-prone areas in four Indonesian provinces, with 200 students in each group. Disaster awareness was assessed before and after a six-month intervention, and the data were analyzed using descriptive statistics, paired- and independent-sample t-tests, effect-size analysis, and N-Gain. Students who received the integrated model demonstrated substantially greater improvement than the control group, with N-Gain scores of 0.89 and 0.27, respectively, and consistently higher gains across all measured dimensions. The findings demonstrated that combining digital resources with locally grounded disaster knowledge and community-based learning could strengthen disaster awareness beyond conventional classroom instruction. This integration provided a context-sensitive approach to elementary disaster education that could be adapted to different sociocultural, disaster-risk, and technological conditions.

A. Introduction

Disasters are not merely environmental events; for children, they can become profound disruptions to safety, education, protection, and social stability. Since 2000, disasters have disrupted the lives of more than one billion children and damaged or destroyed over 80,000 schools worldwide (Munich Re & United Nations Office for Disaster Risk Reduction, 2024; UNESCO, 2024). These figures expose a critical educational challenge: schools are expected to prepare children for hazards that can simultaneously threaten the very environments in which learning and protection occur. Disaster Risk Reduction (DRR) education therefore cannot be treated as supplementary knowledge. It is an essential educational mechanism for developing students' capacity to recognize hazards, understand vulnerability, anticipate risks, and respond appropriately when disasters occur (Amri et al., 2018; Sakurai & Shaw, 2022; Suarmika et al., 2022; Kahar et al., 2026).

Yet disaster education in elementary schools often remains disconnected from the conditions in which children actually encounter risk. Instruction frequently emphasizes textual information and conceptual knowledge while providing limited opportunities for students to relate disaster concepts to local hazards, warning signs, evacuation routes, community experiences, and appropriate responses. Consequently, knowing what a disaster is does not necessarily mean knowing how to recognize danger or act safely when confronted with it. This distinction is particularly important for elementary students, whose disaster awareness must be developed through pedagogies that are contextual, visual, participatory, and experience-based rather than predominantly informational (Winarni & Purwandari, 2018; Kitagawa, 2021; Bachri et al., 2024; Cahyadi et al., 2025; Ali et al., 2026).

Recent scholarship offers three important but largely parallel responses to this challenge. Digital learning has expanded opportunities to visualize hazards and preparedness through multimedia, educational videos, digital maps, simulations, and virtual reality, making complex disaster information more interactive and accessible to students (Liao et al., 2020; Rajabi et al., 2022; Y. Zhang et al., 2024; Jennah et al., 2026; Wahyuni et al., 2026). Local knowledge, by contrast, situates disaster learning within community realities by drawing on local warning signs, collective experiences, evacuation routes, mutual-aid practices, and locally embedded preparedness strategies (Suarmika et al., 2022; Vasileiou et al., 2022; Fajri et al., 2025; Kahar et al., 2026). Community

participation further extends learning beyond the classroom by involving teachers, families, community leaders, and other local stakeholders in the production and circulation of disaster knowledge (Gampell et al., 2024; Harada et al., 2023; Cahyadi et al., 2025; Fajri et al., 2025). Together, these strands demonstrate a broader movement from information-centred disaster education toward learning that is technologically mediated, contextually grounded, and socially situated (Mercer et al., 2010; Fu & Zhang, 2024; Patonah et al., 2025; Jennah et al., 2026).

The problem is that these strands have not developed with equal attention to their pedagogical interdependence. Technology-oriented studies tend to emphasize the effectiveness of media while giving less attention to whether digital content is embedded in students' local knowledge and social realities. Research on local knowledge demonstrates the importance of cultural values and community experience but provides less explanation of how these resources can be pedagogically transformed through digital learning. Community-participation studies establish the value of social engagement, yet the mechanisms through which participation interacts with technology and local knowledge to develop students' disaster awareness remain insufficiently explained (Amri et al., 2018; Sakurai & Shaw, 2022; Shiwaku, 2014; Shoji et al., 2020; Cahyadi et al., 2025; Ali et al., 2026). The unresolved issue, therefore, is not simply whether digital learning, local knowledge, or community participation is beneficial independently, but how their interaction can constitute a coherent pedagogical mechanism for disaster education (Vasileiou et al., 2022; Šakić Trogrlić et al., 2022; Patonah et al., 2025; Jennah et al., 2026).

This limitation leaves both a conceptual and an empirical gap. Existing approaches provide insufficient explanation of how digital mediation, locally embedded knowledge, and community participation can operate collectively to shape disaster awareness among elementary school students. Addressing this gap matters because technology detached from social context risks reducing disaster education to digitalized information, while local knowledge without appropriate pedagogical mediation may remain difficult to translate into structured classroom learning. Likewise, community participation without integration into the learning architecture may remain peripheral rather than becoming part of the educational process (Mercer et al., 2010; Šakić Trogrlić et al., 2022; Fajri et al., 2025; Ali et al., 2026). A more integrated approach is therefore required to connect what students see through digital media, what they know from their local environments, and

what they experience through community social practices (Fu & Zhang, 2024; Cvetković et al., 2024; Cahyadi et al., 2025; Fitari et al., 2026).

This study addresses this problem through the Ethno-Social Community-Based Digital Disaster Learning Model, which brings these three domains into a unified pedagogical framework. Its contribution lies not simply in combining digital learning, local knowledge, and community participation, but in assigning them complementary pedagogical functions: digital technology operates as a mediating tool for visualizing and interacting with disaster risks; ethno-social knowledge provides culturally and locally grounded resources for interpreting those risks; and community participation connects classroom learning with situated social experience. This proposition is theoretically informed by Vygotsky's Sociocultural Theory, which emphasizes learning through social interaction, cultural tools, and mediation, and Wenger's Communities of Practice, which conceptualizes learning through participation in shared social practices (Lave & Wenger, 1991; Vygotsky, 1978; Jennah et al., 2026; Fajri et al., 2025).

The novelty of the study therefore resides in conceptualizing disaster awareness not as an outcome of technology use alone, nor as a product of local knowledge or community engagement independently, but as an outcome potentially strengthened through their pedagogical interaction. This perspective shifts digital disaster education from a technology-centred orientation toward a socially and culturally embedded learning architecture. Such an approach is relevant beyond a single local setting because disaster education globally faces the challenge of translating increasingly available digital technologies into forms of learning that remain responsive to local risk environments and community knowledge (Hoffmann & Muttarak, 2017; Sakurai & Shaw, 2022; Vasileiou et al., 2022; Kahar et al., 2026; Wahyuni et al., 2026).

This study aims to evaluate the effectiveness of integrating digital learning, local knowledge, and community participation in enhancing disaster awareness among elementary school students. Specifically, it examines whether students who participate in the Ethno-Social Community-Based Digital Disaster Learning Model demonstrate greater improvement in disaster awareness than students receiving conventional disaster education.

B. Method

A quantitative approach with a quasi-experimental non-equivalent control group design was employed to evaluate the effectiveness of the Ethno-Social Community-Based

Digital Disaster Learning Model. This design was selected because the natural classroom setting did not permit individual randomization. Both experimental and control groups completed pretests and posttests; the experimental group received the proposed learning model, whereas the control group received conventional disaster education.

The study involved 400 fifth-grade elementary students from disaster-prone areas in four Indonesian provinces: Aceh, North Sumatra, West Sumatra, and the Special Region of Yogyakarta. The experimental and control groups each comprised 200 students. Participants were selected through multistage sampling with purposive criteria. The provinces were selected to represent disaster-vulnerable contexts, followed by schools meeting criteria related to disaster-prone location, availability of fifth-grade classes, administrative approval, and willingness to participate. Existing classes served as group units and were designated as experimental or control groups by considering comparability in grade level, student characteristics, instructional materials, and school readiness.

The intervention was implemented over six months. The experimental group participated in the Ethno-Social Community-Based Digital Disaster Learning Model, which integrated digital learning, local disaster knowledge, and community participation through orientation, community exploration, digital technology-supported learning, collaborative projects, evaluation, and reflection. Digital resources included multimedia presentations, educational videos, and virtual reality, while contextual activities incorporated local disaster experiences, hazard recognition, risk mapping, preparedness strategies, and community-based projects. In contrast, the control group received conventional disaster education through teacher explanations, textbooks, printed materials, classroom discussions, note-taking, and written assessments, without the integration of digital media, virtual reality, local knowledge, or community-based projects. The operational structure of the intervention is presented in Table 1.

Table 1. Logic model for the ethno-social community-based digital disaster learning model

Model Component	Operationalization	Pedagogical Function
Ethno-social resources	Local disaster narratives, community experiences, cultural values, evacuation routes, hazard signs, mutual-aid practices, and community leaders.	Contextualizes disaster learning through local knowledge and cultural resources.
Digital	Multimedia, digital maps, disaster	Visualizes disaster risks, evacuation

Model Component	Operationalization	Pedagogical Function
learning tools	applications, online quizzes, simulations, videos, and virtual reality.	procedures, safe locations, and response strategies.
Community-based learning	Community exploration, interviews, focus groups, risk mapping, simulations, and preparedness projects.	Connects classroom learning with community experiences and preparedness practices.
Learning process	Orientation, community exploration, digital learning, collaboration, projects, evaluation, and reflection.	Integrates contextual, digital, collaborative, and reflective learning.
Measured outcome	Disaster awareness assessed through emotional self-awareness, accurate self-awareness, and self-confidence.	Provides the measured outcome for evaluating pretest–posttest changes and differences between groups.

Disaster awareness was measured using a 140-item questionnaire administered to both groups before and after the intervention. The instrument operationalized disaster awareness through three measured dimensions: emotional self-awareness, accurate self-awareness, and self-confidence. Three instrument experts assessed the questionnaire for content appropriateness, linguistic clarity, alignment between items and their respective indicators, and readability for elementary school students. Empirical validity was subsequently examined through a pilot test involving 100 elementary students using item-total product-moment correlations. All 140 items exceeded the critical r value of 0.195 and were retained for analysis. The instrument demonstrated high internal consistency, with a reliability coefficient of 0.962. Accordingly, the same instrument was used to generate the pretest and posttest scores analyzed at both the overall and indicator levels.

Data were analyzed using SPSS version 31. Descriptive statistics were used to summarize pretest and posttest scores, followed by normality and homogeneity tests to examine statistical assumptions. Paired-sample *t*-tests assessed changes within the experimental and control groups, while an independent-sample *t*-test examined differences between the groups. N-Gain analysis was additionally employed to estimate improvement in students' disaster-awareness scores following the intervention.

The study followed research ethics procedures appropriate to research involving elementary school students. Permission was obtained from participating schools, and school administrators and teachers were informed about the study objectives, procedures, duration, student involvement, and use of the collected data. Students' identities and personal information were kept confidential, and the data were used exclusively for academic purposes. Students were not subjected to harmful treatment or compelled to

provide particular responses, and all research and learning activities were conducted under the supervision of teachers and school authorities.

C. Results and Discussion

This section presents empirical findings on changes in students' disaster awareness following the implementation of the Ethno-Social Community-Based Digital Disaster Learning Model and discusses their theoretical, pedagogical, and broader implications. The results first examine within- and between-group differences, followed by an interpretation of the findings in relation to digital learning, local knowledge, community participation, and disaster risk reduction education.

1. Results

The results present changes in students' disaster awareness following the six-month learning intervention. The analysis examined the distribution of pretest and posttest scores in the experimental and control groups, within-group changes, between-group differences, effect size, and normalized gain (N-Gain). The findings are reported sequentially to provide a clear empirical account of differences in disaster awareness before and after the intervention.

Descriptive statistics were first examined to identify the distribution and changes in disaster awareness scores across the two groups. The experimental and control groups each consisted of 200 students. The descriptive results are presented in Table 2.

Table 2. Summary of questionnaire data for the experimental and control classes

Group	N	Min	Max	Average	Standard Deviation
Pretest Experiment	200	45.71	62.85	47.85	2.398
Posttest Experiment	200	77.85	97.14	94.28	2.492
Pretest Control	200	44.28	63.57	47.14	2.937
Posttest Control	200	55.71	72.14	61.42	2.473

Table 2 shows that the experimental group recorded an increase in mean disaster awareness scores from 47.85 (SD = 2.398) at pretest to 94.28 (SD = 2.492) at posttest, representing a mean increase of 46.43 points. The control group also showed an increase, from 47.14 (SD = 2.937) to 61.42 (SD = 2.473), corresponding to a mean increase of 14.28 points. The pretest means of the two groups were relatively close, whereas a substantial

difference emerged in their posttest means. Thus, descriptively, the increase observed in the experimental group was considerably greater than that recorded in the control group.

Before inferential analyses were conducted, the distribution of the pretest and posttest data was examined using the Kolmogorov–Smirnov normality test. The results for both groups are reported in Table 3.

Table 3. Normality test results

Variable	Group	Statistic	df	Sig.
Disaster Awareness	Pretest Experiment	0.263	200	0.182
Disaster Awareness	Posttest Experiment	0.127	200	0.186
Disaster Awareness	Pretest Control	0.283	200	0.192
Disaster Awareness	Posttest Control	0.273	200	0.127

As presented in Table 3, the reported significance values were 0.182 for the experimental pretest, 0.186 for the experimental posttest, 0.192 for the control pretest, and 0.127 for the control posttest. All reported significance values exceeded the 0.05 threshold. Based on these results, the pretest and posttest distributions were treated as satisfying the normality assumption for the subsequent parametric analyses.

Changes in disaster awareness within each group were subsequently examined using paired-sample t-tests. The results are presented in Table 4.

Table 4. Results of the paired-sample t-test

Data Pairs	Mean Difference	Standard Deviation	Standard Error	t	df	Sig. (2-tailed)
Posttest–Pretest Experiment	46.43	3.84	0.272	170.79	199	<0.001
Control Posttest–Pretest	14.28	3.17	0.224	63.75	199	<0.001

The paired-sample analysis showed statistically significant pretest-to-posttest changes in both groups. In the experimental group, the mean difference was 46.43 (SD = 3.84, SE = 0.272), $t(199) = 170.79$, $p < 0.001$. The control group showed a mean difference of 14.28 (SD = 3.17, SE = 0.224), $t(199) = 63.75$, $p < 0.001$. Although both groups recorded statistically significant increases, the observed mean increase in the experimental group was more than three times that of the control group. These results establish that changes occurred within both groups while showing a substantially larger score increase among students exposed to the experimental intervention.

To quantify the magnitude of the posttest difference between the experimental and control groups, an effect-size analysis was conducted using Cohen's *d*. The results are summarized in Table 5.

Table 5. Results of the effect size analysis

Comparison	Mean Difference	Pooled SD	Cohen's d	Category
Experimental Posttest vs. Control Posttest	32.86	2.48	13.24	Very large

As shown in Table 5, the posttest mean difference between the experimental and control groups was 32.86 points, with a pooled standard deviation of 2.48. The resulting Cohen's *d* was 13.24, which was classified as a very large effect according to the categorization applied in the study. This statistic describes the magnitude of the observed separation between the posttest scores of the two groups; statistical significance of the between-group difference was examined separately through the independent-sample *t*-test.

Prior to the between-group analysis, homogeneity of variance was examined. The results of the homogeneity test are reported in Table 6.

Table 6. Results of the homogeneity test

Testing Basis	Statistics	df1	df2	Sig.
Based on Mean	1.514	1	398	0.219
Based on the Median	0.391	1	398	0.532
Based on the median and adjusted df	0.987	1	112.928	0.321
Based on the Trimmed Mean	1.596	1	398	0.207

Table 6 reports a significance value of 0.219 based on the mean, which was greater than 0.05. The additional estimates based on the median, adjusted degrees of freedom, and trimmed mean also produced significance values above 0.05. Accordingly, the variance assumption was treated as satisfied, and the equal-variances-assumed result was used for the independent-sample *t*-test.

The independent-sample *t*-test was then used to examine the post-intervention difference in disaster awareness scores between the experimental and control groups. The results are presented in Table 7.

Table 7. Results of the independent-sample t-test

Variable	Variance Assumption	F	Sig. Levene	t	df	Sig. (2-tailed)

Disaster Awareness	Equal variances assumed	1.514	0.219	132.34	398	<0.001
Disaster Awareness	Equal variances not assumed			132.34	397.87	<0.001

The analysis revealed a statistically significant difference between the experimental and control groups, $t(398) = 132.34$, $p < 0.001$, using the equal-variances-assumed estimate. This result corresponds to the posttest mean difference reported earlier, with the experimental group obtaining a mean score of 94.28 compared with 61.42 in the control group. Thus, the inferential analysis confirmed that the post-intervention disaster awareness scores differed significantly between the two groups.

In addition to the significance tests, N-Gain analysis was conducted to quantify the relative improvement in disaster awareness scores from pretest to posttest. The results are presented in Table 8.

Table 8. Results of the N-Gain test for students' disaster awareness

Group	Pre-test Mean	Posttest Mean	Difference	N-Gain	Percentage N-Gain	Category
Experimental	47.85	94.28	46.43	0.89	89.03%	High
Control	47.14	61.42	14.28	0.27	27.01%	Low

The experimental group achieved an N-Gain of 0.89 (89.03%), categorized as high, whereas the control group obtained an N-Gain of 0.27 (27.01%), categorized as low. These results are consistent with the descriptive score changes: the experimental group increased by 46.43 points, compared with 14.28 points in the control group. The difference in the pretest-to-posttest patterns across the two groups is visualized in Figure 1.

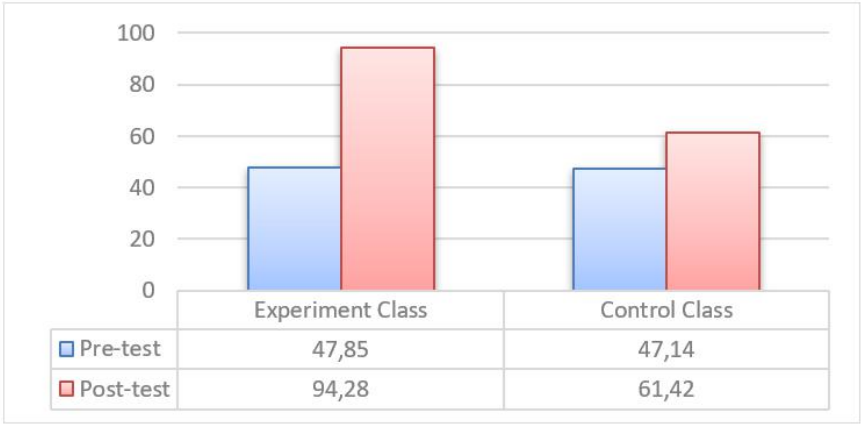

Figure 1. Difference in mean pretest and posttest scores between the experimental group and the control group

Figure 1 visually demonstrates the contrasting score trajectories of the two groups. Although their pretest means were similar (47.85 for the experimental group and 47.14 for the control group), their posttest scores diverged substantially, reaching 94.28 and 61.42, respectively. The figure therefore provides a visual representation of the larger pretest-to-posttest increase observed in the experimental group.

To provide a more detailed account of the observed improvement, N-Gain scores were further examined across the three indicators used in the disaster awareness questionnaire: emotional self-awareness, accurate self-awareness, and self-confidence. The indicator-level results are presented in Table 9.

Table 9. N-Gain Results for Disaster Awareness Based on Indicators

Indicator	Experiment Class		Control Class	
	N-Gain	Category	N-Gain	Category
Emotional Self-Awareness	0.88	High	0.25	Low
Accurate self-awareness	0.89	High	0.30	Low
Self-confidence	0.90	High	0.26	Low
Average	0.89	High	0.27	Low

Table 9 shows consistently higher N-Gain scores across all three indicators in the experimental group. Self-confidence recorded the highest N-Gain (0.90), followed by accurate self-awareness (0.89) and emotional self-awareness (0.88); all were categorized as high. In comparison, the control group recorded N-Gain values of 0.30 for accurate self-awareness, 0.26 for self-confidence, and 0.25 for emotional self-awareness, all categorized as low. The average indicator-level N-Gain was therefore 0.89 for the experimental group and 0.27 for the control group. Overall, the results consistently show a larger increase in the experimental group at both the aggregate disaster awareness level and across each of the three measured indicators.

2. Discussion

The findings indicate that elementary school students who participated in the Ethno-Social Community-Based Digital Disaster Learning Model demonstrated substantially greater improvement in measured disaster awareness than those who received conventional disaster education. The significance of this difference lies not merely in the use of digital technology, but in the integration of digital mediation, locally embedded knowledge, and community participation within a single learning

process. Experience-based and technology-supported approaches can strengthen students' engagement with disaster-related learning (Arıkan et al., 2024; Çakir & Kilcan, 2022), particularly when students are given opportunities to interact with disaster-related situations rather than receiving information passively (Winarni et al., 2021; Xu & Dai, 2022). The present findings extend this perspective by suggesting that digital learning becomes more educationally meaningful when technological experiences are connected to the social, cultural, and environmental contexts in which students understand disaster risk (Cahyadi et al., 2025; Rizal et al., 2025).

Digital learning appears to be one mechanism through which this improvement can be understood. For elementary school students, disaster-related concepts such as hazards, evacuation routes, safe zones, and emergency situations may remain abstract when presented predominantly through lectures or textbooks. Multimedia presentations, educational videos, simulations, and virtual reality can provide more concrete and interactive representations of situations that cannot safely be experienced directly. Rajabi et al., (2022) demonstrate the potential of immersive environments for disaster-related learning, while technology-supported approaches can facilitate students' engagement with complex situations through visualization and interaction (Ahmadi et al., 2024; Shujuan et al., 2022; Agusnaya et al., 2024; Asyhari & Komikesari, 2024). Similar arguments concerning digitally mediated learning are advanced by M. Zhang and Wang (2022). Digital technology in this study should therefore be understood not simply as a mechanism for delivering information, but as a mediating resource that connects abstract disaster-related concepts with situations that students can visualize and engage with (Cahyadi et al., 2025).

The pedagogical value of this mediation becomes stronger when digital representations are connected to students' local environments. Community narratives, local hazard indicators, evacuation routes, safe locations, mutual-aid practices, and historical disaster experiences provide resources through which formal knowledge can be interpreted in relation to everyday life. The importance of connecting scientific and local knowledge has long been recognized in disaster risk reduction (Mercer et al., 2010), particularly because risk is understood and negotiated within particular social and cultural settings (Rasyid et al., 2023; Anam et al., 2025). Walshe and Nunn (2012) similarly demonstrate the educational relevance of culturally situated knowledge, while Šakić Trogrlić et al., (2022) emphasize the importance of integrating local

knowledge into disaster risk reduction (Kartono et al., 2024; Fajri et al., 2025). Vasileiou et al., (2022) further reinforce the value of contextual knowledge in understanding and responding to risk. Within the present model, local knowledge is therefore not supplementary cultural content; it functions as a pedagogical resource that enables students to connect digitally represented risks with places, experiences, and practices that are socially recognizable to them (Rizal et al., 2025; Fajri et al., 2025).

Community participation further extends this contextualization by moving disaster-related learning beyond the boundaries of the classroom. Community exploration, collaborative activities, risk mapping, preparedness projects, and reflection expose students to socially situated forms of knowledge and demonstrate that responses to disaster are embedded within collective practices (Ikhsan et al., 2025; Ximenes et al., 2024). Fu and Zhang (2024) emphasize the value of linking learning with community participation, while Harada et al., (2023) show the relevance of community engagement within disaster-related learning. The involvement of teachers, families, community leaders, and other local actors can therefore connect formal education with experiences that conventional instructional materials may not fully represent (Sumarsono et al., 2025; Ikhsan et al., 2025). Such interaction also creates possibilities for intergenerational learning (Carlos Rodrigo et al., 2024) and for disaster knowledge to circulate between schools and communities (Shoji et al., 2020). Schools, from this perspective, become interfaces between formal learning and the wider social environments in which disaster knowledge is produced, shared, and practiced (Rasyid et al., 2023; Ximenes et al., 2024).

The indicator-level findings provide a more specific understanding of the observed improvement. Higher gains were recorded across emotional self-awareness, accurate self-awareness, and self-confidence, with self-confidence showing the largest improvement. These findings should not be interpreted as direct evidence that students had already developed specific preparedness behaviors or would necessarily respond effectively during an actual disaster. Rather, they indicate changes in the personal and affective dimensions captured by the instrument. The improvement in self-confidence may be associated with opportunities to participate actively in simulations, risk discussions, safety-related activities, and community-based projects. Confidence and self-efficacy have been associated with individuals' perceived capacity to engage with emergency situations (Demiray et al., 2024; Patel et al., 2023), while

Janatri (2023) similarly highlights the relevance of personal capacities within disaster preparedness. Active engagement may therefore offer students opportunities to develop greater confidence in understanding and positioning themselves in relation to disaster-related situations (Wahyuni et al., 2025; Agusnaya et al., 2024).

The changes in accurate and emotional self-awareness complement this pattern. Within the measurement framework used in this study, accurate self-awareness concerns students' recognition of their capabilities, limitations, and roles in disaster-related situations. This dimension is relevant because responses to risk are rarely entirely individual; they are shaped by information, social relationships, and coordinated action. Education itself has an important role in shaping disaster preparedness (Hoffmann & Muttarak, 2017), while preparedness is also embedded within wider social and community contexts (Cvetković et al., 2024; Gouda & Yang, 2023; Wang et al., 2021; Ximenes et al., 2024). Emotional self-awareness adds another dimension because disaster-related situations may evoke fear, anxiety, panic, and uncertainty among children. Structured visualizations, reflective discussions, and community narratives can provide controlled educational spaces in which students encounter and reflect on such situations. The relevance of psychological and affective dimensions in disaster-related learning has been identified by Kaya and Ayker (2023), Kılıç Bayageldi and Şimşek (2022), and Pacheco et al., (2021), while immersive and digital environments can provide additional forms of mediated experience (Rajabi et al., 2022; Shujuan et al., 2022; Wahyuni et al., 2025; Agusnaya et al., 2024). Nevertheless, the present findings remain evidence of improvement in measured emotional self-awareness rather than direct evidence of emotional performance during real disasters.

The improvement observed in the control group is equally important for interpreting the findings. Conventional learning through lectures, reading, classroom discussion, and written assessment was also associated with increased disaster-awareness scores. The distinction is therefore not between an effective and an ineffective approach, but between different magnitudes of improvement associated with different learning arrangements. Conventional instruction can provide foundational disaster-related information, whereas the experimental model adds opportunities to observe, visualize, discuss, map, collaborate, practice, and reflect. Active and experiential approaches have similarly been associated with stronger

engagement in disaster education (Çakir & Kilcan, 2022; Xu & Dai, 2022), while Winarni and Purwandari (2018) and Arslan and Karakuş (2024) illustrate the educational value of involving learners more actively in disaster-related learning (Asyhari & Komikesari, 2024; Cahyadi et al., 2025). The larger improvement in the experimental group can thus be interpreted as reflecting a broader learning architecture in which information is connected with experience, context, and social participation rather than as evidence that technology alone is superior to conventional instruction (Sumarsono et al., 2025).

This pattern is theoretically consistent with Vygotsky's sociocultural understanding of learning, in which knowledge develops through interaction with cultural tools, language, and social environments. Mediation occupies a central position within this perspective (Daniels, 2002), while socially mediated learning emphasizes the importance of interaction and scaffolding in knowledge development (Eun & E. Knotek, 2022). In the present model, digital resources operate as mediating tools, local knowledge provides culturally situated resources, and teachers and community members form part of the social environment through which students engage with disaster-related situations (Rasyid et al., 2023; Fajri et al., 2025). Students are consequently positioned as active participants in meaning-making rather than merely recipients of predetermined information, which also reflects a constructivist understanding of learning (Taber, 2024). The educational value of technology, from this perspective, cannot be separated from the cultural resources and social relationships through which students interpret and use it (Cahyadi et al., 2025; Rizal et al., 2025; Kartono et al., 2024).

The same process can be understood through the communities of practice perspective, which views learning as participation in socially meaningful practices rather than solely as individual acquisition of information (Lave & Wenger, 1991). Environmental exploration, risk mapping, preparedness discussions, and community-based projects situate disaster learning within activities that extend beyond formal classroom instruction (Ikhsan et al., 2025; Ximenes et al., 2024). Shoji et al., (2020) connect disaster-related learning with wider educational and social processes, while Fu and Zhang (2024) emphasize the importance of community participation in creating meaningful learning experiences (Sumarsono et al., 2025). Disaster awareness in this model can therefore be understood as developing through an interaction

between mediated learning and participation: students engage with digitally represented knowledge while simultaneously relating that knowledge to local environments, community experiences, and collective practices (Anam et al., 2025; Rizal et al., 2025).

Rather than treating digital learning, local knowledge, and community participation as independent instructional additions, the findings point to their complementary pedagogical functions. Digital technology provides opportunities for visualization and interaction (M. Zhang & Wang, 2022; Asyhari & Komikesari, 2024), while local knowledge situates disaster risks within culturally and geographically meaningful environments (Vasileiou et al., 2022; Rasyid et al., 2023; Fajri et al., 2025; Kartono et al., 2024). Community participation, in turn, connects learning with social experience and collective practice (Fu & Zhang, 2024; Ikhsan et al., 2025; Sumarsono et al., 2025). What distinguishes the present model is therefore not any single component, but the way these elements operate together within one learning architecture. From this perspective, disaster education moves beyond information transmission toward learning in which technological mediation, cultural context, and social participation reinforce one another (Cahyadi et al., 2025).

Such an integrated learning architecture brings disaster education into dialogue with several disciplinary perspectives. Digital mediation draws on educational technology and learning sciences (Agusnaya et al., 2024; Asyhari & Komikesari, 2024), while local knowledge connects formal learning with sociocultural knowledge and practices embedded in students' communities (Suarmika et al., 2022; Vasileiou et al., 2022; Fajri et al., 2025; Rizal et al., 2025; Kartono et al., 2024). Community participation further links learning with families, local leaders, and other social actors (Gampell et al., 2024; Harada et al., 2023; Sumarsono et al., 2025; Ikhsan et al., 2025), while changes in self-awareness and self-confidence introduce a psychological dimension. Disaster education therefore cannot be reduced to educational technology alone. Digital resources need to be connected to locally relevant risks, community experiences, and preparedness practices. Such contextualization reflects the broader social dimensions of preparedness (Cvetković et al., 2024; Šakić Trogrlić et al., 2022; Anam et al., 2025; Hadisi et al., 2025; Hamdi et al., 2025) and enables collaboration among schools, families, communities, and disaster-

management stakeholders to extend learning beyond classroom boundaries (Ximenes et al., 2024).

The relevance of this pedagogical architecture extends beyond Indonesia, particularly to disaster-prone educational contexts in low- and middle-income countries. Disasters continue to threaten children's safety and educational continuity internationally (Munich Re & United Nations Office for Disaster Risk Reduction, 2024; UNESCO, 2024), reinforcing the importance of education in strengthening disaster preparedness (Hoffmann & Muttarak, 2017). Effective DRR education, however, requires more than transmitting disaster information; it must connect learning with students' social and environmental contexts (Amri et al., 2018; Sakurai & Shaw, 2022; Anam et al., 2025; Hadisi et al., 2025; Ximenes et al., 2024). The model therefore need not depend on identical technological configurations across countries. Schools can adapt digital resources, local knowledge, and community participation to their available capacities (Shiwaku, 2014; Cahyadi et al., 2025; Sumarsono et al., 2025). Cross-context application should consequently be adapted to local disaster profiles, cultural practices, languages, teacher capacities, community structures, and school infrastructure rather than replicating the Indonesian intervention unchanged (Rasyid et al., 2023; Rizal et al., 2025; Hamdi et al., 2025).

Several limitations define the boundaries within which these findings should be interpreted. The participants were fifth-grade students drawn from disaster-prone areas in four Indonesian provinces, and the multistage sampling procedure incorporated purposive criteria; consequently, the findings should not be generalized automatically to other educational levels, regions, or national contexts. The quasi-experimental non-equivalent group design also limits strong causal inference because participants were not individually randomized. In addition, the six-month intervention does not establish whether the observed changes are sustained over longer periods. Disaster awareness was assessed through a self-report questionnaire, meaning that the findings represent measured responses rather than demonstrated behavior during actual disaster situations. Finally, implementation may vary according to teacher readiness, digital facilities, community support, local characteristics, and regional disaster profiles. These limitations delimit the empirical claims of the study while highlighting the contextual conditions that should be considered when interpreting and transferring the model.

D. Conclusion

This study demonstrates that integrating digital learning, local knowledge, and community participation within the Ethno-Social Community-Based Digital Disaster Learning Model is associated with greater improvement in elementary students' disaster awareness than conventional disaster education. Beyond the observed differences between the experimental and control groups, the central finding is that disaster education becomes more meaningful when technological mediation is connected to locally situated knowledge and socially embedded learning experiences. Digital resources enable students to visualize and interact with disaster-related situations, while local knowledge contextualizes those situations within familiar environments and community participation connects classroom learning with collective practices. The findings therefore support a shift from predominantly information-oriented disaster education toward a more contextual, participatory, and socially mediated learning architecture.

The study contributes to disaster education by demonstrating how three approaches that are frequently treated separately—digital learning, local knowledge, and community participation—can operate as complementary pedagogical mechanisms. This integration extends the educational application of sociocultural learning and communities of practice by positioning technology as a mediating tool rather than the central determinant of learning, while recognizing local knowledge and social participation as integral components of disaster education. Practically, the model provides a framework for schools to connect disaster-related curricula with local risks, community experiences, and available digital resources. Its broader relevance lies in the adaptability of these principles across disaster-prone educational contexts, although implementation should remain responsive to local cultures, hazard profiles, technological capacity, and school–community relationships.

Future research should address the empirical boundaries identified in this study. Studies involving different educational levels, regions, disaster profiles, and sociocultural settings are needed to examine the transferability of the model beyond fifth-grade students in the participating Indonesian provinces. Longitudinal research should determine whether improvements in disaster awareness are sustained over time, while mixed-methods designs could clarify how students, teachers, families, and communities

experience and negotiate the learning process. Future studies should also incorporate behavioral or performance-based measures alongside self-reported awareness and employ research designs that better account for participant allocation and classroom or school-level clustering.

Finally, effective disaster education is not determined by how much technology is introduced into the classroom, but by how meaningfully learning connects technology with the places, knowledge, relationships, and practices through which children understand risk. Preparing children for disasters therefore requires education that is not only digitally supported, but also locally grounded, socially connected, and educationally meaningful.

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Declaration of Competing Interest

The authors declare no conflicts of interest related to this research. There are no financial, personal, institutional, or other relationships that could have influenced the research design, data collection, data analysis, interpretation of findings, or manuscript preparation.

Declaration of Generative AI

Grammarly was utilized during manuscript preparation to enhance grammar, clarity, and readability. All outputs from the tool were thoroughly reviewed and edited by the authors, who retain full responsibility for the article's content. All substantive intellectual contributions, including conceptualization, analysis, data interpretation, and final decisions regarding content, arguments, and conclusions, were made solely

by the authors. The authors assume full responsibility for the integrity, originality, and academic quality of this article.

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